EP 28045 (1) AB

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 April 2002 (11.04.2002)

PCT

(10) International Publication Number
WO 02/29981 A2

(51) International Patent Classification[7]: H04B

(21) International Application Number: PCT/US01/31224

(22) International Filing Date: 5 October 2001 (05.10.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/238,298	6 October 2000 (06.10.2000)	US
60/238,297	6 October 2000 (06.10.2000)	US
60/238,296	6 October 2000 (06.10.2000)	US
09/849,441	4 May 2001 (04.05.2001)	US
09/848,968	4 May 2001 (04.05.2001)	US

(71) Applicant: **ALPHION CORPORATION** [US/US]; 4 Industrial Way West, Eatontown, NJ 07724 (US).

(72) Inventors: **SARATHY, Jithamithra**; 10 Ocean Avenue, Apt. 8C, Atlantic Highlands, NJ 07716 (US). **DAVE, Bharat**; 19 Cripple Creek Road, Howell, NJ 07731 (US). **STEFANOV, Boris**; 691 Meyersville Road, Gillette, NJ 07933 (US). **SIMPRINI, Ronald**; 40 Sunrise Place, Red Bank, NJ 07701 (US). **THAI, Tan**; 8 Sugarpine Drive, Jackson, NJ 08527 (US). **ANTOSIK, Roman**; 10 Oxford Key, Colts Neck, NJ 07722 (US). **LIDSKY, David, B.**; 42 Waterview Way, Sea Bright, NJ 07760 (US). **ENGIN, Doruk**; 28 Riverside Avenue #10 F, Red Bank, NJ 07701 (US). **KIM, Kwang**; 8 Fowler Court, Red Bank, NJ 07701 (US).

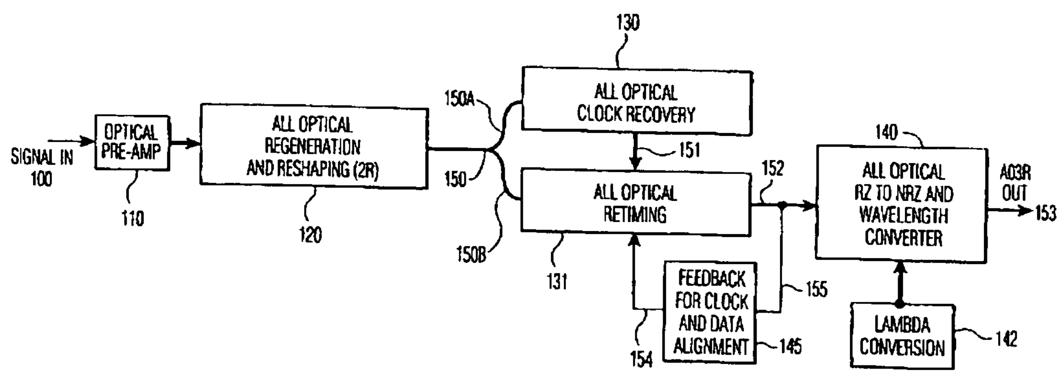
(74) Agent: **HALEVA, Aaron, S.**; Kaplan & Gilman, L.L.P., 900 Route 9 North, Woodbridge, NJ 07095 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,

[Continued on next page]

(54) Title: BIT-RATE AND FORMAT INSENSITIVE ALL-OPTICAL CIRCUIT FOR RESHAPING, REGENERATION AND RETIMING OF OPTICAL PULSE STREAMS



(57) Abstract: A method and system for AO3R functionality is presented. The system includes an AO2R device followed by an AOCR clock recovery module and an AOR retiming device. The AOR retiming device takes as input a recovered clock signal extracted from the output of the AO2R by the AOCR clock recovery module. The output is the recovered clock signal gated by the regenerated and reshaped input signal, and a monitor circuit is used to set the optimum operations of the retiming device. In a first embodiment the output of the AOR retiming device is fed to an AOC code and wavelength conversion output stage, which returns the signal to the NRZ coding, on a service wavelength converted to match the fixed wavelength connection with the DWDM transmission system. In a second embodiment the code conversion is incorporated into the AOR retiming device, and wavelength conversion is accomplished in the AOCR clock recovery device. Previous schemes for performing the O3R functionality use some level of Optical-to-electronic (OEO) conversion to generate the clock signal. The AO3R scheme presented here carries out all three functions in the optical domain, and returns a clean output signal using identical coding as the input, on a wavelength of choice. A lossy, component, such as an optical cross-connect switch can be placed either before the AO3R device or inside of it after the AO2R device and before the signal is split to the AOCR clock recovery and the AOR retiming devices.

WO 02/29981 A2

Application Specific Integrated Circuits (ASICs). A laser source is then

WO 02/29981 PCT/US01/31224

As a consequence of the above, the clock recovery in these network elements must be tunable over a wide range of frequencies. What is needed therefore, is an AO3R system, that is truly all-optical, and that is tunable over a wide range of bit-rate frequencies and works in the carrier frequency range (wavelength range) of the modern telecommunications systems, the C and L wavelength bands.

SUMMARY OF THE INVENTION

A method and system for AO3R functionality is presented. The system includes an AO2R device followed by an AOCR clock recovery module and an AOR retiming device. The AOR retiming device takes as input a recovered clock signal extracted from the output of the AO2R by the AOCR clock recovery module. The output is the recovered clock signal gated by the regenerated and reshaped input signal, and a monitor circuit is used to set the optimum operations of the retiming device. In a first embodiment the output of the AOR retiming device is fed to an AOC code and wavelength conversion output stage, which returns the signal to the NRZ coding, on a service wavelength converted to match the fixed wavelength connection with the DWDM transmission system. In a second embodiment the code conversion is incorporated into the AOR retiming device, and wavelength conversion is accomplished in the AOCR clock recovery device.

Previous schemes for performing the O3R functionality use some level of Optical-to-electronic (OEO) conversion to generate the clock signal. The

domain, and returns a clean output signal using identical coding as the input, on a wavelength of choice.

A lossy component, such as an optical cross-connect switch can be placed either before the AO3R device or inside of it after the AO2R device and before the signal is split to the AOCR clock recovery and the AOR retiming devices.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a schematic diagram of the system of the present invention according to a first embodiment;

Figure 2 depicts a schematic diagram of the all-optical clock recovery stage depicted in Figure 1;

Figure 3 depicts the feedback circuit for data/clock phase alignment according to the present invention;

Figure 4 depicts the cross section of an exemplary SOA-AMZI device according to the present invention;

Figure 5 depicts a schematic view of a fully integrated AO3R subsystem according to a first embodiment of the present invention, indicating the various blocks;

Figure 6 depicts the subsystem of Figure 5, without the block identifiers;

Figure 7 depicts a schematic diagram according to a second embodiment of the present invention;

Figure 8 depicts a first instance of a second embodiment of the fully integrated AO3R subsystem; and

Figure 9 depicts a second instance of a second embodiment of the fully integrated AO3R subsystem.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A schematic diagram of the AO3R device is shown in Figure 1. The input stage 110 comprises an optical amplifier to boost the incoming signal. The all-optical 2R device that follows 120 essentially removes the noise from the boosted signal and reshapes it into a square wave with a high extinction ratio. This device can be implemented in many ways. Commercially available devices that use a Semiconductor Optical Amplifier-Mach Zehnder Interferometer (SOA-MZI) can be utilized for this purpose. Other embodiments that take advantage of four-wave mixing non-linearities in fiber and SOA can also be used for this purpose.

The signal is then split into two parts, as depicted at point 150 in the figure. The splitting ratio can range from -3dB to –10dB. One part of the signal 150A is input into a clock recovery module 130, and the other part of the signal 150B is input into an all-optical retiming (AOR) module 131. The clock recovery module 130 is an all-optical device. There is no conversion of the optical signal into the electrical domain. The device and method of such all-optical clock recovery are discussed in detail in U.S. Patent Application No. 09/849,441. The preprocessor extracting the line rate comprising the first stage of the clock recovery module is discussed in detail in U.S. Patent Application No. 09/848,968.

A schematic description of the clock recovery is shown in Figure 2. The NRZ to PRZ line rate recovery pre-processor 250 forms the first stage of the AOCR scheme. This consists of a path-delayed Asymmetric Mach-Zehnder Interferometer (AMZI). The AMZI incorporates Semiconductor Optical Amplifiers (SOAs) 205, 206 in each of the arms and a phase delay 207 in one of the arms. The line delay is set so that the phase difference between the arms is π. The AMZI is set for destructive interference of the signals in the two paths. Consequently, the interference of a high bit with its path delayed and π-phase inverted copy, generates an RZ-like bit, termed a PRZ bit, at both the leading and falling edges of the original high bit. This latter signal, with a bit rate effectively double that of the original NRZ bit rate, is the PRZ output signal.

This effective doubling of the bit rate leads to the generation of a large component of the line rate frequency in the RF spectrum of the output signal 210 of the AMZI 250. Generally, unless the input signal is exceptionally aberrant, this line rate frequency will be the far and away dominant frequency in the spectrum. Since the preprocessor does not need to know *a priori* the actual bit rate or coding of the input data to operate, the extraction of the line rate is data rate and format insensitive. For obvious reasons, it is wavelength insensitive as well.

Thus the preprocessor has the ability to reshape the PRZ signal as well as adjust its duty cycle. The output 210 of the first stage 250 becomes the input to the second stage 260. In a preferred embodiment, the second stage 260 comprises a symmetric Mach-Zehnder Interferometer, where each arm contains a semiconductor optical amplifier 211 and 212, respectively.

The principle of clock recovery is based on inducing oscillations between the two lasers DFB1 213 and DFB2 214. The oscillations are triggered by the output of the first stage 210. As described above, this output can be either RZ or PRZ. The current to DFB2 214 is tuned close to its lasing threshold, with DFB1 213 energized so as to be in lasing mode. Thus the trigger pulse 210 induces lasing in DFB2 214. The feedback from DFB2 214 turns off the lasing in DFB1 213 resulting in DFB2 214 itself turning off. The reduced feedback from DFB2 214 now returns DFB1 213 to lasing. In this manner the two lasers mutually stimulate one another in oscillation. Recalling that the dominant frequency in the input signal 210 is the original signal's 200 clock rate, pulses from the input 210 are sufficient to lock the oscillation of the DFB lasers at that rate, and, in general, to hold for quite a number of low bits (such as would appear where the original signal 200 had a long run of high bits). Thus, the forced triggering by the PRZ/RZ input 210 locks the phase of the oscillations at the original signal's 200 clock rate.

The interferometer improves the control of the phase input to DFB2 214. The use of the SOA-MZI facilitates the tuning of the oscillation rate by adjusting the input signal phase into DFB2 214. As the phase of the MZI output is

tuned, the gain recovery time of DFB2 214 is adjusted. This results in the oscillation rate being altered. In this manner the clock frequency can be further tuned to the desired line rate. Using non-linear SOA elements also allows shaping of the output clock with a lesser energy expenditure. Moreover, by adjusting the currents in each of the two SOAs in the second stage interferometer, the refractive index of each SOA's waveguide can be manipulated, thus altering the phase of the pulse entering DFB2 214 thus adjusting the phase of the oscillations to align it to the phase of the retimed input signal, 152 in Figure 1. Thus, the oscillation rate and phase of the circuit can be altered. The identical circuit can be tuned to the various bit rates available in the network, thus rendering a system that is bit rate independent.

Referring again to Figure 1, as above, the second part of the signal 150B derived from the AO2R 120 is input into the AOR retiming device 131 along with the line rate clocking signal 151, which was recovered in the AOCR clock recovery module 130 and output therefrom, the process of which being as depicted in Figure 2. In the AOR the clocking signal 151 is AND gated with the regenerated and reshaped input signal 150B, to give the output 152 of the AOR 131. A feedback circuit 145 ensures that the clock signal 151 and the data signal 152 are phase aligned. This feedback circuit 145 can be implemented, for example, by a simple photodetector-based circuit that monitors the DC power level at the output of the AOR 152 to ensure that the signal level is maximized, as shown in Figure 3. The monitor signal 155, seen as 355 in Figure 3, passes to the photodetector and peak detector, 345 in Figure 3 (corresponding to the feedback circuit 145 in Figure 1), generating

a negative feedback signal 354, corresponding to signal 154 in Figure 1. The negative feedback from this feedback circuit tunes the static phase condition of the AOR (i.e. by adjusting the tuning currents controlling the SOAs in the MZI of the AOR, as described below) such that the detected photocurrent is a maximum. This indicates an optimum phase shift between the original signal 100 and the recovered clock 151 in the AOR retiming circuit.

The output of the AOR 131 is fed into the all-optical RZ to NRZ and wavelength converter 140. A CW (continuous wavelength) laser source in the coding converter is utilized to execute wavelength conversion. This functionality is depicted by the Lambda Conversion module 142 in Figure 1.

Recalling the functionality of the AOCR module, as described in United States Patent Application Nos. 09/849,441 and 09/848,968, the clock recovery transforms an NRZ input signal to a PRZ signal. If the network is set up to run NRZ coded data, the output has to be transformed back to NRZ coding. As well, network conditions and provisioning may desire that the input data signal be carried on a different outgoing wavelength than the one that brought it in. Thus, wavelength conversion is supplied at the output stage. In an alternative embodiment, as described below, the wavelength conversion can be accomplished in the AOCR device 130, and the code conversion integrated into the AOR device 131, obviating devices 140 and 142 in Figure 1.

A lossy component, such as an optical cross-connect switch, can be placed either before the AO3R device or inside of it after the AO2R device and before the signal is split to the AOCR clock recovery and the AOR retiming devices.

The use of a commercial AOCR device 130 predicates a modular structure to the overall AO3R scheme as shown in Figure 1. One embodiment of this assembly can be a multi-chip module (MCM) based on the Silicon Optical Bench (SiOB) technology. In such an embodiment the interconnection between the individual chips that make up the four main components, i.e. AO2R 120, AOCR 130, AOR 131 and AOC RZ/NRZ and Wavelength Converter 140, each of which utilizes the same symmetrical MZI with SOAs in each arm structure, is provided by silica waveguides on a silicon substrate.

A preferred embodiment of the AO3R can be a completely integrated sub-system on an InP substrate. This would imply that the structure of the AO2R would consist of an SOA-MZI integrated with a laser, and the similar structures would be composed of SOA-MZIs integrated with lasers as required by their function (e.g., AOCR, Wavelength Converter). Such an integration is similar to the implementation of an AOCR as discussed in U.S. Patent Application No. 09/849,441.

As discussed above, the method of the invention can be implemented using either discrete components, or in a preferred embodiment, as an integrated device in InP-based semiconductors. The latter embodiment will next be described with reference to Fig. 4.

Fig. 4 depicts a cross section of an exemplary integrated circuit SOA. With reference to Figure 2, Figure 4 depicts a cross section of any of the depicted SOAs taken perpendicular to the direction of optical signal flow in the interferometer arms. Numerous devices of the type depicted in Figure 4 can easily be integrated with the interferometers of the preprocessor, the closck recovery so that the entire circuit can be fabricated on one IC. The device consists of a buried sandwich structure 450 with an active Strained Multiple Quantum Well region 411 sandwiched between two waveguide layers 410 and 412 made of InGaAsP. In an exemplary embodiment, the λ_g of the InGaAsP in layers 410 and 412 is 1.17μm. The sandwich structure does not extend laterally along the width of the device, but rather is also surrounded on each side by the InP region 404 in which it is buried.

The active Strained MQW layer is used to insure a constant gain and phase characteristic for the SOA, independent of the polarization of the input signal polarization. The SMQW layer is made up of pairs of InGaAsP and InGaAs layers, one disposed on top of the other such that there is strain between layer interfaces, as is known in the art. In a preferred embodiment, there are three such pairs, for a total of six layers. The active region/waveguide sandwich structure 450 is buried in an undoped InP layer 404, and is laterally disposed above an undoped InP layer 403. This latter layer 403 is laterally disposed above an n-type InP layer 402 which is grown on top of a substantially doped n-type InP substrate. The substrate layer 401 has, in a preferred embodiment, a doping of 4-6 x $10^{18}/cm^{-3}$. The doping of the grown

layer 402 is precisely controlled, and in a preferred embodiment is on the order of $5 \times 10^{18}/cm^{-3}$. On top of the buried active region/waveguide sandwich structure 450 and the undoped InP layer covering it 304 is a laterally disposed p-type InP region 421. In a preferred embodiment this region will have a doping of $5 \times 10^{17}/cm^{-3}$. On top of the p-type InP region 421 is a highly doped p+-type InGaAs layer. In a preferred embodiment this latter region will have a doping of $1 \times 10^{19}/cm^{-3}$. The p-type layers 420 and 421, respectively, have a width equal to that of the active region/waveguide sandwich structure, as shown in Fig. 4. As described above, the optical signal path is perpendicular to and heading into the plane of Fig. 4.

Utilizing the SOA described above, the entire all-optical 3R device can be integrated in one circuit. With reference to Figure 5, a schematic layout of an exemplary fully integrated AO3R device is shown. It is noted that for ease of viewing Figure 5 only shows the active parts of the circuit, Thus, devices with redundant structures could be used in any of the depicted modules. As well, Figure 5 has blocks drawn around the portions of the circuit comprising the various devices and modules depicted schematically in Figure 1. Thus, the two figures can be easily correlated. The integrated device depicted in Figure 5 implements all of the various functionalities of Figure 1, as will next be discussed.

There are four stages in the integrated device, corresponding to the AO2R stage 120, the Clock Recovery stage 130 (which includes the pre-processor stage), the AOR stage 131, and the AOC RZ/NRZ code and wavelength

converter stage 140, of Figure 1. In general the reference numbers in Figures 1 and 5 are identical in the tens and digits places, again for ease of correlation.

At the top of Figure 5 appear the input signal 500, the pre-amplifier 510 and the AO2R stage 520. The incoming signal 500 enters at the top right of the figure, and passes through SOA 510. From there it enters the MZI, with integrated laser, of stage 520. The output from the AO2R stage then bifurcates, into signals 550A and 550B. Output 550B, now a regenerated and reshaped optical pulse train goes into the clock recovery stage 530, comprising the preprocessor 530PP and the clock extraction 530CE sub-stages. As described in the Parent Applications, if the original input was RZ coded the gain of the upper arm of the AMZI in stage 520 is set to zero, and intermediate signal 550I is RZ coded as well. If the original was NRZ coded, intermediate signal 550I is PRZ coded. The intermediate output from the preprocessor 550I is fed into the clock extraction sub-stage 530CE, which outputs the now RZ coded clock signal 551 (also possibly having undergone wavelength conversion via DFB-2R laser 560, according to a second embodiment of the invention, described below). This latter signal 551 is input to the AOR stage 531, along with the split output 550A from stage 520, which is the data signal, and is input to the AOR at SOA 570. This input 550A gates, through phase modulation in the MZI containing SOAs 571 and 572, the clock signal 551 to generate the retimed output of this stage, 552.

AOR output signal 552 is an RZ coded signal. This signal 552 is input to the code and wavelength conversion module 540. When the input signal 500 is NRZ coded, the AOR output signal 552 is fed to the MZI 590, comprising SOAs 575 and 576, through both SOAs 573 and 574. An undelayed (via SOA 573) high bit phase modulates the continuous wavelength light from DFB-2R 542 for constructive interference (as the SOAs 575 and 576 are initially set to a relative phase shift of π (in general all SOAs in opposite arms of MZIs are so set); thus a high bit in the upper arm changes the phase difference between the two SOAs to zero, and a high bit on each SOA changes the relative phase shift back to π), and the CW light combines at the output 553 to generate a "1." When the high bit through the upper arm of MZI 590 has passed, SOA 574 then passes the delayed copy of that same bit to the MZI via delay element 580.

Using an appropriate delay, depending, inter alia, on the phase shift latency in the SOAs and the full period bit-rate of the recovered clock signal, the RZ signal is converted to an NRZ coded signal.

In this manner an NRZ pulse is generated from an incoming RZ pulse 552. When the input signal 552 is RZ coded, SOA 574 is turned off, thus blocking the delayed signal to the MZI 590 code converter. The converter thus passes the RZ pulses unchanged to the system output 553.

Wavelength conversion of the regenerated, reshaped and retimed signal 552 is achieved by tuning the frequency of the DFB laser 542. The sampled power monitor, PM 545, is sent to the feedback controller, as described above, and used to set the tuning current in SOAs 571 and 572.

The net result is the final output 553 of the entire AO3R device, which is a clean, regenerated, reshaped, and retimed optical pulse train, on a wavelength chosen by the user.

Fig. 6 is identical to Figure 5, but is made more readable by removal of the blocks denoting the various stages. The reference numbers are identical to those in Figure 5, except that the hundreds place digit is a "6" in Figure 6, replacing the "5" in such index numbers from their Figure 5 counterparts.

An exemplary method of effecting such an integrated AO3R device is next described.

After an epiwafer is grown with the waveguide and the SOA active regions, the wafer is patterned to delineate the SOAs, the AMZI and the various MZIs. In a preferred embodiment the path length difference between the two arms of the AMZI in the clock-extraction sub-stage is approximately 1mm.

Next, the DFB regions of the second stage of the device are created using either a holographic or a non-contact interference lithographic technique. The periodicity of the grating in a preferred embodiment is approximately 2850A.

The grating is of Order 1 and provides optical feedback through second-order diffraction. The undoped InP top cladding layer, the p-type InP layers, and the contact layer are then regrown on the patterned substrate. This step is then followed by photolithography for top-contact metallization. The device is then cleaved and packaged.

A second embodiment of the invention is depicted in Figures 7-9. In a second embodiment of the invention the RZ to NRZ conversion is implemented by the AOR retiming device. This eliminates the need for the AOC device 540 in Figure 5. In this case the wavelength conversion is achieved by tuning carrier frequencies of the DFB lasers #1 and #2 in the clock extraction device of the AOCR, 530CE. Figure 7 shows a functional block diagram for this case. Similar index numbers (in the tens and units digits) in Figures 7 and Figure 1 correlate to similar functionalities. In Fig. 7 lambda conversion 742 is now done in the AOCR module 730, and RZ/NRZ conversion in the AOR retiming module 731.

There are two instances, or versions of this second embodiemtn, depicted in Figures 8 and 9, respectively. Figure 8 shows the counter-propagating implementation of the AOR/RZ-to-NRZ-conversion device. In this configuration the delayed input signal 850A and the delayed recovered clock signal 851 inputs to the AOR 831 must be both delayed by the same amount for the RZ-to-NRZ conversion, as described above, thus delay elements 880 and 880'.

Figure 9 shows the co-propagating implementation of the AOR/RZ-to-NRZ-conversion device. In this configuration only one delay 980 is required for the coupled input and recovered clock signals. In this implementation both the retimed and converted output 951, and the regenerated input signal 950A are transferred to the output of the AOR device. In this configuration an optical filter 999 is required to filter-out the regenerated input signal 950A, 950AA, 950AB.

While the above describes the preferred embodiments of the invention, various modifications or additions will be apparent to those of skill in the art. Such modifications and additions are intended to be covered by the following claims.

WHAT IS CLAIMED:

1. A method of all-optical regeneration, reshaping and retiming of optical data signals comprising:

   a regeneration and reshaping stage;

   a clock recovery stage; and

   a code and wavelength conversion stage.

2. The method of claim 1, where the method is insensitive to the bit rate and coding method of the input signal.

3. The method of claim 2, where the method is insensitive to the wavelength of the input signal.

4. The method of claim 3, where the method works in at least the carrier frequency range of the C and L wavelength bands.

5. An all-optical regeneration, reshaping and retiming device, comprising

   four Mach-Zehnder interferometers;

   one asymmetric Mach-Zehnder interferometer; and

   four light sources.

6. The device of claim 5, where the light sources emit continuous wavelength light.

7. The device of claim 6, where the light sources are distributed feedback lasers.

8. The device of claim 7, where there are SOAs in each arm of the inteferometers.

9. The device of any of claims 5-8, where there is

an AO2R first stage, comprising an MZI;

a clock recovery second stage comprising

an AMZI; and

an MZI integrated with two light sources;

an all-optical retiming third stage; and

a code and wavelength conversion fourth stage.

10. An all-optical regeneration, reshaping and retiming device, comprising

three Mach-Zehnder interferometers;

one asymmetric Mach-Zehnder interferometer; and

three light sources.

11. The device of claim 10, where the light sources emit continuous wavelength light.

12. The device of claim 11, where the light sources are distributed feedback lasers.

13. The device of claim 12, where there are SOAs in each arm of the inteferometers.

14. The device of any of claims 10-13, where there is

an AO2R first stage, comprising an MZI;

a clock recovery second stage comprising

an AMZI; and

an MZI integrated with two light sources; and

an all-optical retiming and code conversion third stage;

15. The device of claim 14, where wavelength conversion is done in the second stage.

16. The device of claim 15, where within the third stage the recovered clock signal and the data signal co-propogate.

17. The device of claim 16, where within the third stage the recovered clock signal and the data signal counter-propogate.

18. A semiconductor device comprising:

an InP substrate of a first doping type;

a second InP layer of the first doping type disposed upon it;

a third InP layer not doped disposed upon said second layer;

a first InGaAsP waveguide region laterally disposed on top of said third InP layer, whose width is less than that of the substrate, first and second InP layers;

an active strained multiple quantum well ("SMQW") region laterally disposed and centered on top of said first waveguide region, having the same width as said first waveguide region;

a second InGaAsP waveguide region laterally disposed on top of said SMQW layer, having the same width as said first waveguide region and as said SMQW region;

a fourth InP layer, undoped, disposed upon said second waveguide region, and extending downward, in the direction of the substrate, along the sides of said active region and said first waveguide region, whose width is equal to that of the substrate, and the first and second InP layers;

a first InP layer of a second doping type, laterally disposed above said fourth InP layer, having the same width as said first waveguide region and as said SMQW region;

a second InP layer of the second doping type, laterally disposed above said first InP layer of the second doping type, having the same width as said first InP layer of the second doping type;

a contact layer laterally disposed above said second InP layer of the second doping type; and

a metal electrode disposed above said contact layer.

19. The device of claim 15, where the SOAs comprise the device of claim 18.

20. The device of claim 16, where the SOAs comprise the device of claim 18.

21. The device of claim 17, where the SOAs comprise the device of claim 18.

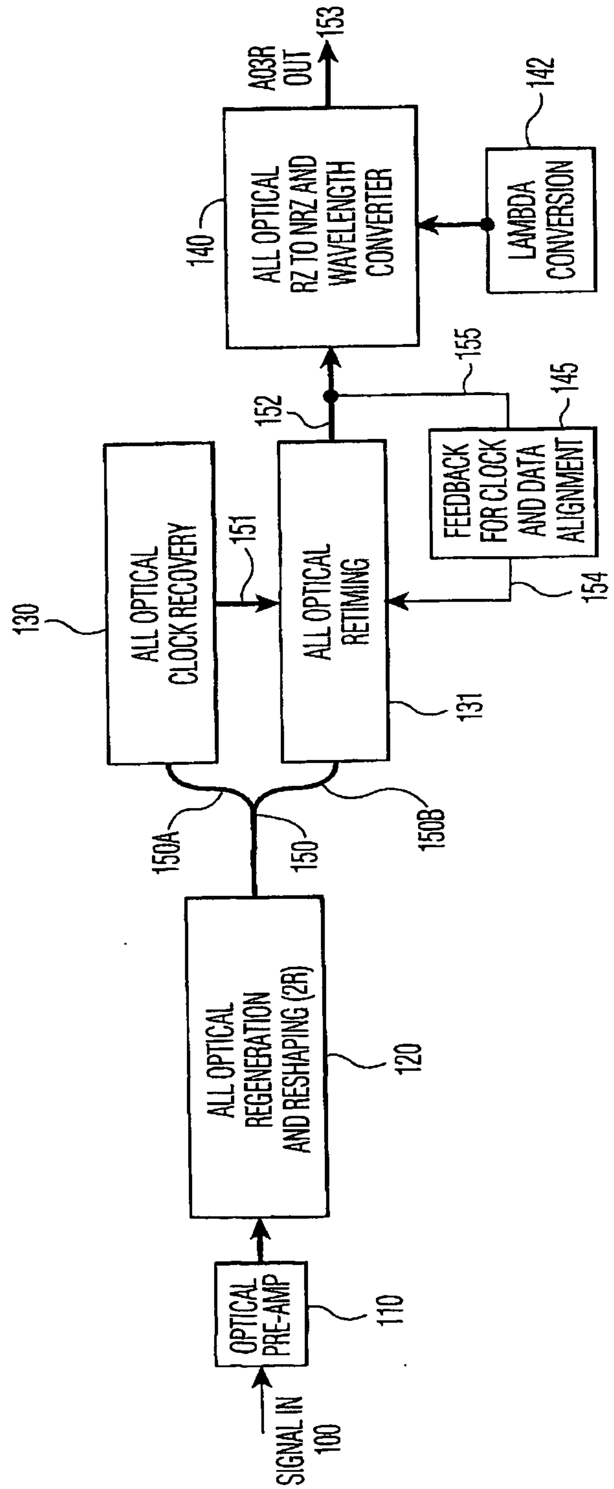

SIGNAL IN
100
OPTICAL
PRE-AMP
110
ALL OPTICAL
REGENERATION
AND RESHAPING (2R)
120
150
150A
150B
ALL OPTICAL
CLOCK RECOVERY
130
151
ALL OPTICAL
RETIMING
131
154
FEEDBACK
FOR CLOCK
AND DATA
ALIGNMENT
145
152
155
ALL OPTICAL
RZ TO NRZ AND
WAVELENGTH
CONVERTER
140
LAMBDA
CONVERSION
142
A03R
OUT
153

FIG. 1

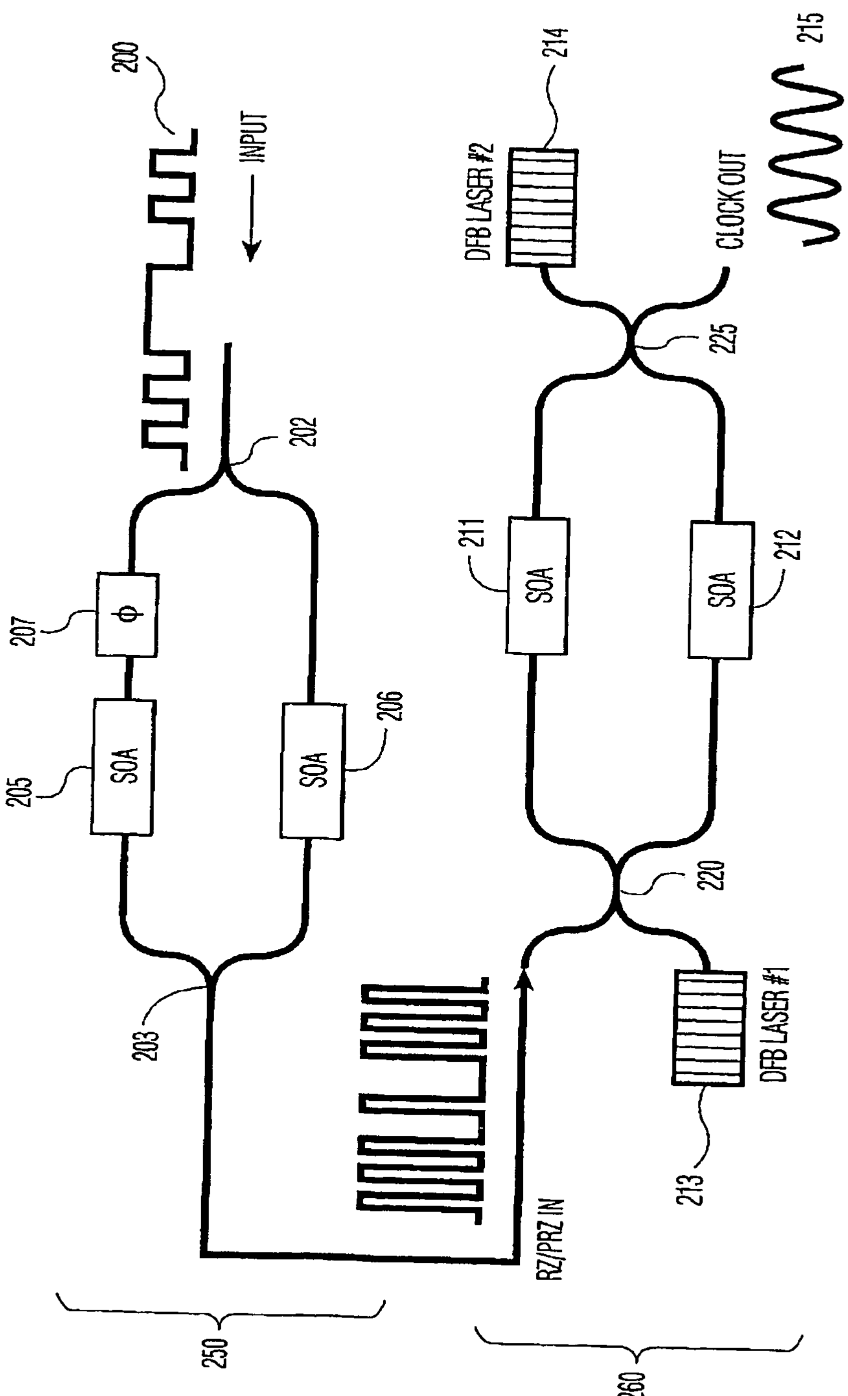

200
INPUT
202
207
ϕ
205
SOA
206
SOA
203
RZ/PRZ IN
250
214
DFB LASER #2
215
CLOCK OUT
225
211
SOA
212
SOA
220
DFB LASER #1
213
260

FIG. 2

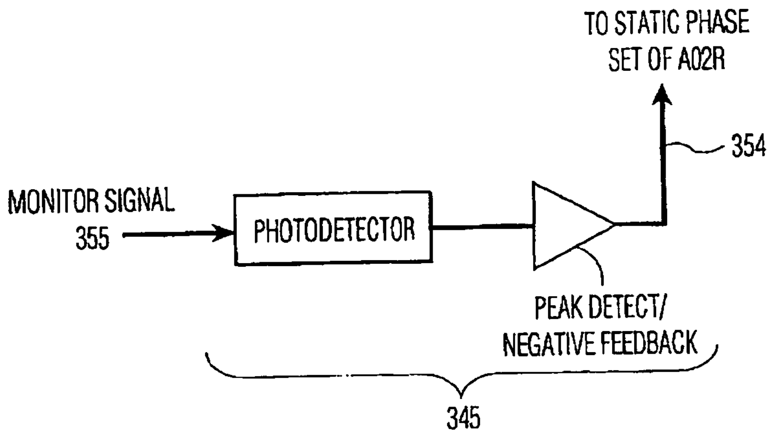

TO STATIC PHASE
SET OF A02R
354
MONITOR SIGNAL
355
PHOTODETECTOR
PEAK DETECT/
NEGATIVE FEEDBACK
345

FIG. 3

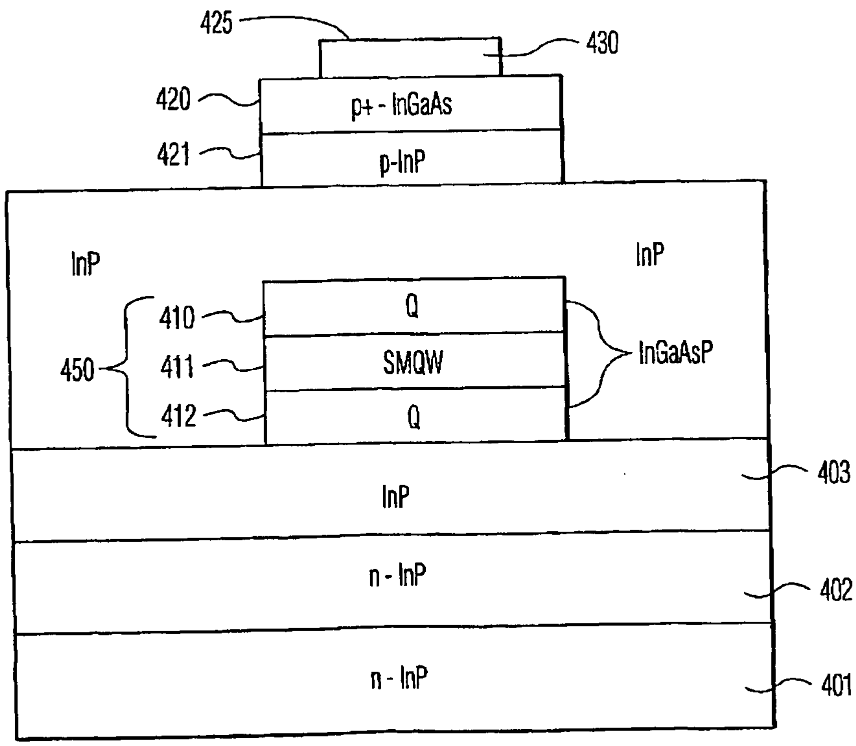

425
430
420
p+ - InGaAs
421
p-InP
InP
InP
410
Q
450
411
SMQW
InGaAsP
412
Q
InP
403
n - InP
402
n - InP
401

FIG. 4

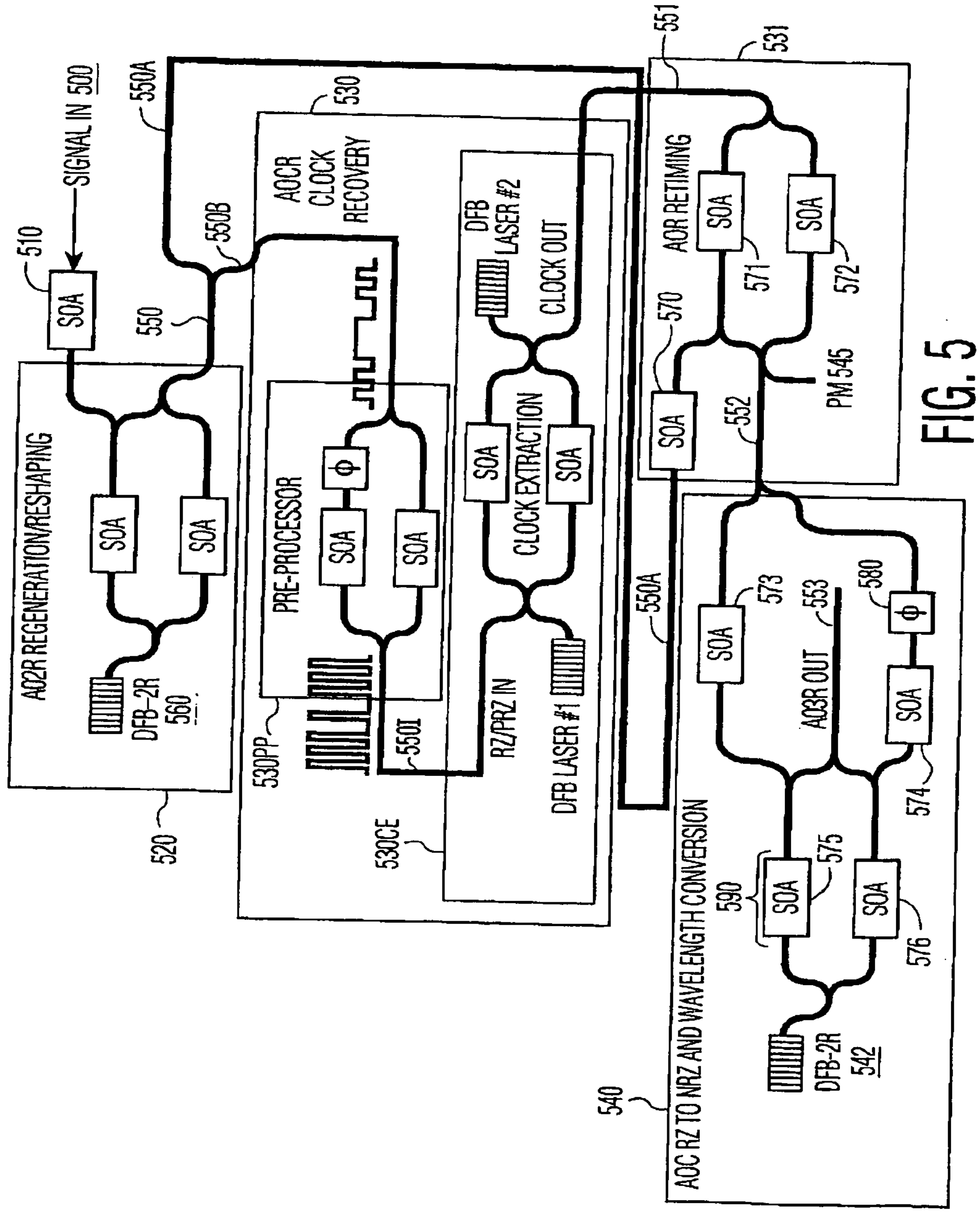

SIGNAL IN 500
510
SOA
550A
550B
550
A02R REGENERATION/RESHAPING
SOA
SOA
DFB-2R
560
520
AOCR
CLOCK
RECOVERY
530
PRE-PROCESSOR
SOA
SOA
ϕ
530PP
550I
530CE
DFB
LASER #2
CLOCK OUT
SOA
SOA
CLOCK EXTRACTION
RZ/PRZ IN
DFB LASER #1
550A
551
531
AOR RETIMING
SOA
SOA
571
572
570
SOA
552
PM 545
AOC RZ TO NRZ AND WAVELENGTH CONVERSION
540
SOA
573
553
580
ϕ
A03R OUT
SOA
574
590
SOA
575
SOA
576
DFB-2R
542

FIG. 5

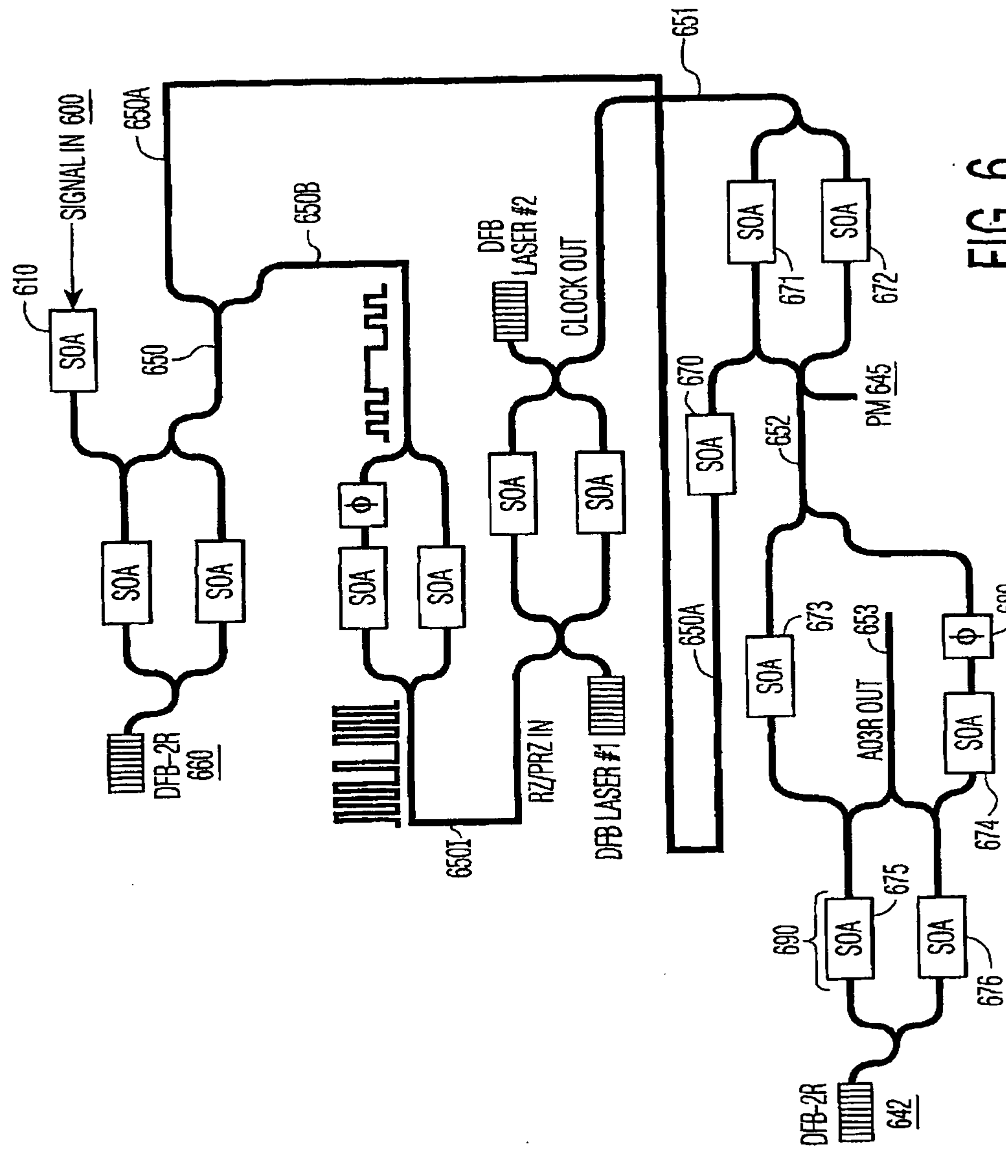

SIGNAL IN 600
610
SOA
650
650A
650B
SOA
SOA
DFB-2R
660
Φ
SOA
SOA
650I
RZ/PRZ IN
DFB LASER #1
DFB
LASER #2
CLOCK OUT
SOA
SOA
650A
651
670
SOA
SOA
671
SOA
672
PM 645
652
673
SOA
653
AO3R OUT
680
Φ
SOA
674
690
SOA
675
SOA
676
DFB-2R
642

FIG. 6

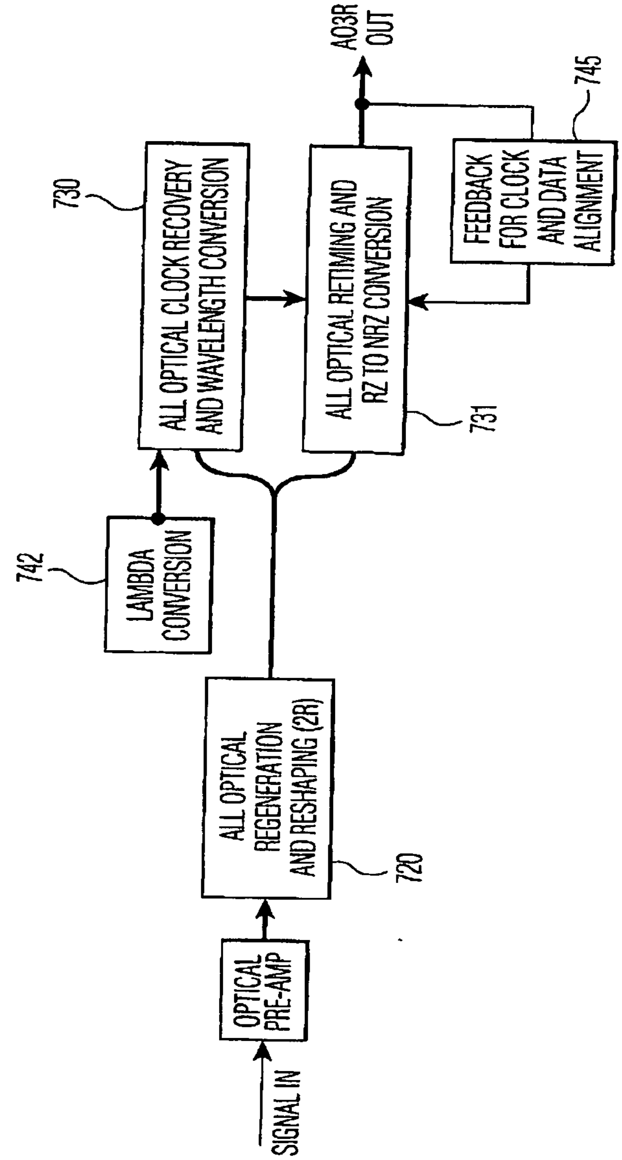

SIGNAL IN
OPTICAL PRE-AMP
ALL OPTICAL REGENERATION AND RESHAPING (2R)
720
LAMBDA CONVERSION
742
ALL OPTICAL CLOCK RECOVERY AND WAVELENGTH CONVERSION
730
ALL OPTICAL RETIMING AND RZ TO NRZ CONVERSION
731
FEEDBACK FOR CLOCK AND DATA ALIGNMENT
745
AO3R OUT

FIG. 7

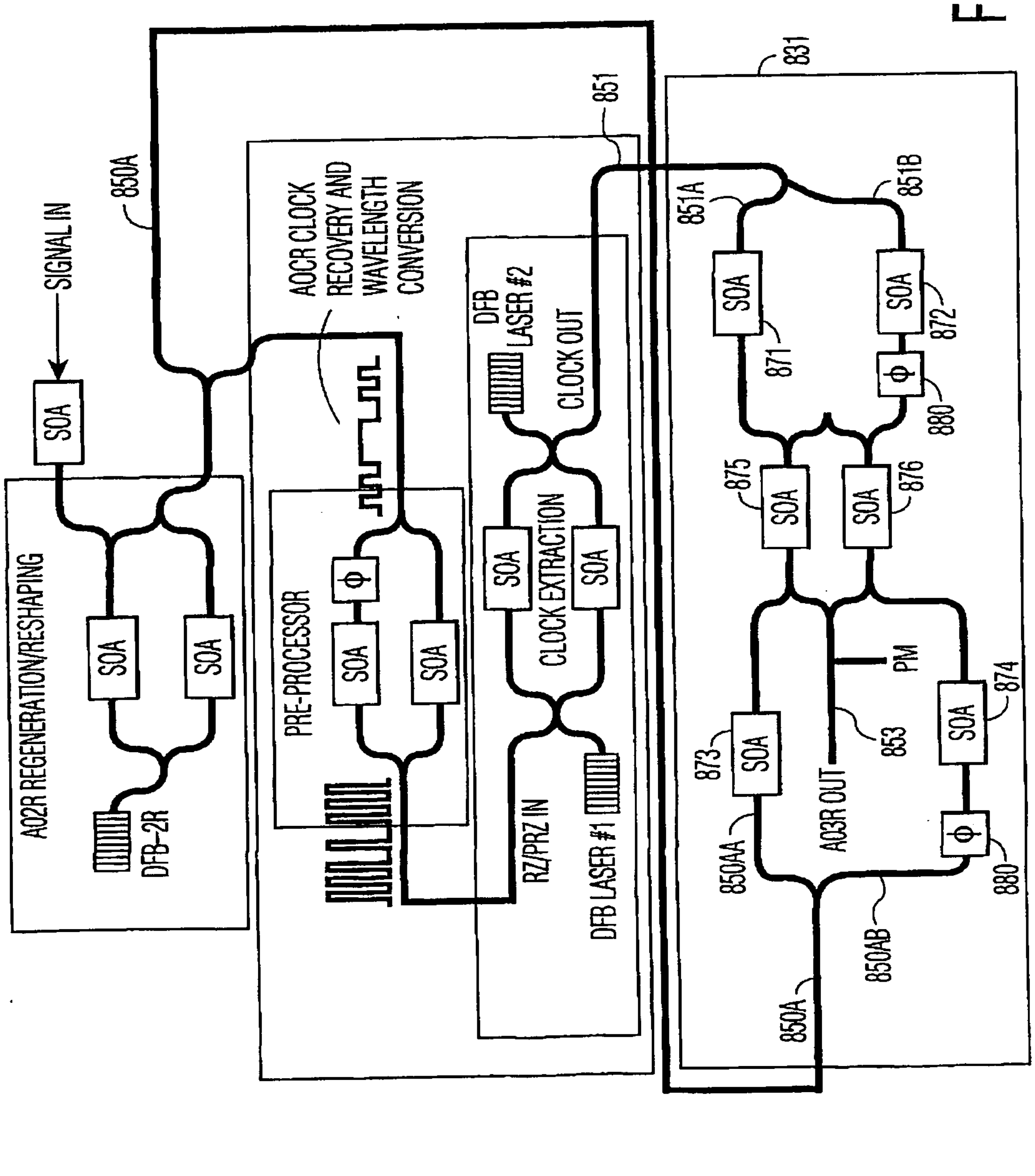

SIGNAL IN
SOA
850A
A02R REGENERATION/RESHAPING
SOA
SOA
DFB-2R
AOCR CLOCK RECOVERY AND WAVELENGTH CONVERSION
PRE-PROCESSOR
SOA
SOA
DFB LASER #2
CLOCK OUT
CLOCK EXTRACTION
SOA
SOA
RZ/PRZ IN
DFB LASER #1
851
831
851A
851B
SOA
SOA
871
872
880
875
876
SOA
SOA
PM
853
873
874
SOA
SOA
A03R OUT
850AA
850AB
880
850A

FIG. 8

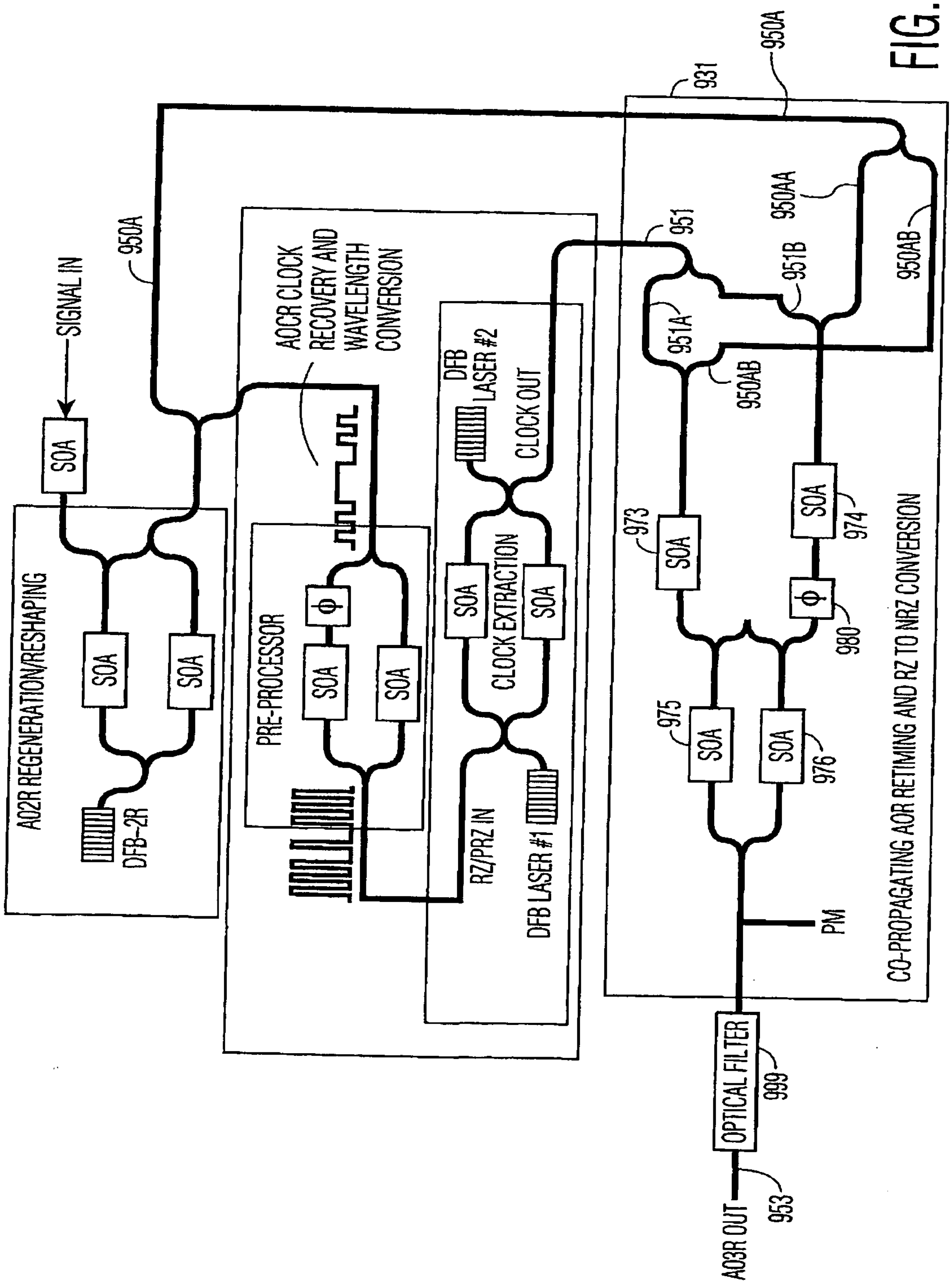

SIGNAL IN
SOA
950A
AO2R REGENERATION/RESHAPING
SOA
SOA
DFB-2R
AOCR CLOCK RECOVERY AND WAVELENGTH CONVERSION
PRE-PROCESSOR
ϕ
SOA
SOA
DFB LASER #2
CLOCK OUT
SOA
SOA
CLOCK EXTRACTION
RZ/PRZ IN
DFB LASER #1
931
950A
950AA
950AB
951
951B
951A
950AB
973
SOA
SOA
974
ϕ
980
975
SOA
SOA
976
PM
CO-PROPAGATING AOR RETIMING AND RZ TO NRZ CONVERSION
OPTICAL FILTER
999
AO3R OUT
953

FIG. 9

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 April 2002 (11.04.2002)

PCT

(10) International Publication Number
WO 02/029981 A3

(51) International Patent Classification⁷: G02B 6/293

(21) International Application Number: PCT/US01/31224

(22) International Filing Date: 5 October 2001 (05.10.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/238,298	6 October 2000 (06.10.2000)	US
60/238,297	6 October 2000 (06.10.2000)	US
60/238,296	6 October 2000 (06.10.2000)	US
09/849,441	4 May 2001 (04.05.2001)	US
09/848,968	4 May 2001 (04.05.2001)	US

(71) Applicant: **ALPHION CORPORATION** [US/US]; 4 Industrial Way West, Eatontown, NJ 07724 (US).

(72) Inventors: **SARATHY, Jithamithra**; 10 Ocean Avenue, Apt. 8C, Atlantic Highlands, NJ 07716 (US). **DAVE, Bharat**; 19 Cripple Creek Road, Howell, NJ 07731 (US). **STEFANOV, Boris**; 691 Meyersville Road, Gillette, NJ 07933 (US). **SIMPRINI, Ronald**; 40 Sunrise Place, Red Bank, NJ 07701 (US). **THAI, Tan**; 8 Sugarpine Drive, Jackson, NJ 08527 (US). **ANTOSIK, Roman**; 10 Oxford Key, Colts Neck, NJ 07722 (US). **LIDSKY, David, B.**; 42 Waterview Way, Sea Bright, NJ 07760 (US). **ENGIN, Doruk**; 28 Riverside Avenue #10 F, Red Bank, NJ 07701 (US). **KIM, Kwang**; 8 Fowler Court, Red Bank, NJ 07701 (US).

(74) Agent: **HALEVA, Aaron, S.**; Kaplan & Gilman, L.L.P., 900 Route 9 North, Woodbridge, NJ 07095 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report: 10 April 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 02/029981 A3

(54) Title: BIT-RATE AND FORMAT INSENSITIVE ALL-OPTICAL CIRCUIT FOR RESHAPING, REGENERATION AND RETIMING OF OPTICAL PULSE STREAMS

(57) Abstract: A method and system for AO3R functionality is presented. The system includes an AO2R device followed by an AOCR clock recovery module and an AOR retiming device. The AOR retiming device takes as input a recovered clock signal extracted from the output of the AO2R by the AOCR clock recovery module. The output is the recovered clock signal gated by the regenerated and reshaped input signal, and a monitor circuit is used to set the optimum operations of the retiming device. In a first embodiment, the output of the AOR retiming device is fed to an AOC code and wavelength conversion output stage, which returns the signal to the NRZ coding, on a service wavelength converted to match the fixed wavelength connection with the DWDM transmission system. In a second embodiment, the code conversion is incorporated into the AOR retiming device, and wavelength conversion is accomplished in the AOCR clock recovery device.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/31224

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : 375/371
US CL : G02B 006/293
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : G02B 006/293

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
IEEE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Dulk et al. Frequency Converison and Analysis. CLEO 2000. 7-12 May 2000. pgs. 276-277. especially pgs. 277, last line of column 1.	1-4
Y	Raybon et al. 20 Gbit/s all-optical regeneration and wavelength conversion using SOA based interferometers. OFC/IOOC '99 Technical Digest. 21-26 February 1999. pgs. 27-29. vol. 4. especially fig. 1.	6-17
X	US 5,798,852 A (Billes et al.) 25 August 1998 (25.08.1998). especially fig. 2.	1-4
A		6-17
X	Lavigne et al. All-Optical 3R Regeneration. LEOS 2000. 13-16 November 2000. pgs. 407-408. vol. 2. especially fig. 1.	1-4
A	Li et al. Nonlinear Dynamics for All-Optical 3R Regneration. LEOS 2000. 13-16 November 2000. pgs. 521-522. vol. 2. fig. 1.	1-17
A	Saxena et al. All-optical 3R regeneration and wavelength conversion in an integrated SOA/DFB laser: experiment and simulation. LEOS 2000. 10-15 September 2000. pg. 1.	1-17

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 June 2002 (24.06.2002)	23 DEC 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Thomas H Tarcza Telephone No. 703-308-1113

Form PCT/ISA/210 (second sheet) (July 1998)

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Otani et al. Optical 3R regenerator using wavelength converters based on electroabsorption modulator for all-optical network applications. IEEE Photonics Technology Letters, vol. 12, no. 4, April 2000. pgs. 431-433. figures 1 and 3.	5-17
Y	Wolfson et al. 40-Gb/s all-optical wavelength conversion, regeneration, and demultiplexing in an SOA-based all-active mach-zehnder interferometer. IEEE Photonics Technology Letters, vol. 12, no. 3, March 2000. pgs. 332-334. fig. 1.	5-17
A	Devaux, Fabrice. All-optical 3R regenerators: Status and challenges. IEEE 2000. pgs. 5-6. fig. 1.	1-17
A	JP 41-1101922A (NEC Corp.) 13 April 1999 (13.04.1999) . fig. 1.	1-17
A	EP 0901245 A1 (Morthier et al.) 03 October 1999 (03.10.1999). fig. 4.	5-17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/31224

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Please See Continuation Sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.: 1-17

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims, it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

Continuation of Item 4 of the first sheet:
The title is too long. The following is the new title: BIT-RATE AND FORMAT INSENSITIVE ALL OPTICAL 3R CIRCUIT.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING
Group 1, claim(s) 1-4, drawn to a method of all optical regeneration.

Group 2, claim(s) 5-17, drawn to an optical interferometer.

Group 3, claim(s) 18-20, drawn to a semiconductor optical amplifier.

- Group 1 is a method with the special technical feature of all optical regeneration.

- Group 2 is an apparatus with the special technical feature of amplifying arms.

- Group 3 is an apparatus with the special technical feature of a semiconductor composition.

All of the groupings are directed to a method or apparatus for a bit rate and format insensitive all optical circuit for reshaping, regeneration, and retiming of optical pulse streams but each group has a different special technical feature not shared by the remaining groups.